

Exam in power electronics 2018-05-30 8-13

Means of assistance: Calculator
Grades: 20-30 p: 3
31-40 p: 4
41-50 p: 5

In total 5 exercises

1 The DC-DC buck converter

- a) Draw a 1QC buck converter connected to the dc side of a three phase diode rectifier, which is connected to the power grid. The dclink capacitor and protection against too high inrush currents should be included in the drawing. The transistor is of IGBT-type. (1 p.)
- b) The three-phase grid, to which the three phase diode rectifier is connected, has the line-to-line voltage $400\text{ V}_{\text{rms}}$ and the frequency 50 Hz. Calculate the dc output voltage and the maximum dc link voltage from the rectifier. (1 p.)
- c) Calculate the rms-current and the average current through one rectifying diode (see figure 1). Calculate the rectifier diode losses. The diode threshold voltage is 1.0 V and the differential resistance is 2.0 mohm. (2 p.)
- d) Calculate the losses of the IGBT transistor and of the free wheeling diode in the buck converter. The buck converter phase inductor is 0.6 mH, and its resistance can be neglected. Draw a time diagram with the buck converter phase current versus time during one period of the switching frequency. The load on the low voltage side of the buck converter is a battery with the voltage 400 V_{dc} . The switching frequency is 2 kHz. The threshold voltage of the IGBT transistor equals 1.0 V and its differential resistance equals 1.4 mohm. The turn-on loss of the IGBT transistor equals 45 mJ and its turn-off loss equals 72 mJ. These turn-on and turn-off losses are nominal values at 900 V dclink voltage and 180 A turn-on and turn-off current. The threshold voltage of the free wheeling diode equals 1. V and the differential resistance of this diode equals 2 mohm. The free wheeling diode turn-on losses can be neglected and its turn-off losses equals 30 mJ, at 900 V dclink voltage and 180 A turn off current. (4 p.)
- e) Which is the junction temperature of the IGBT transistor and of the free wheeling diode, and which is the junction temperature of the rectifying diodes? The thermal resistance of the heatsink equals 0.065 K/W? The thermal resistance of the IGBT transistor equals 0.08 K/W? The thermal resistance of the free wheeling diode equals 0.2 K/W? The thermal resistance of the rectifier diode equals 0.25 K/W? The ambient temperature is 35 °C. The rectifier diodes and the buck converter transistor and diode share the heatsink. (2 p.)

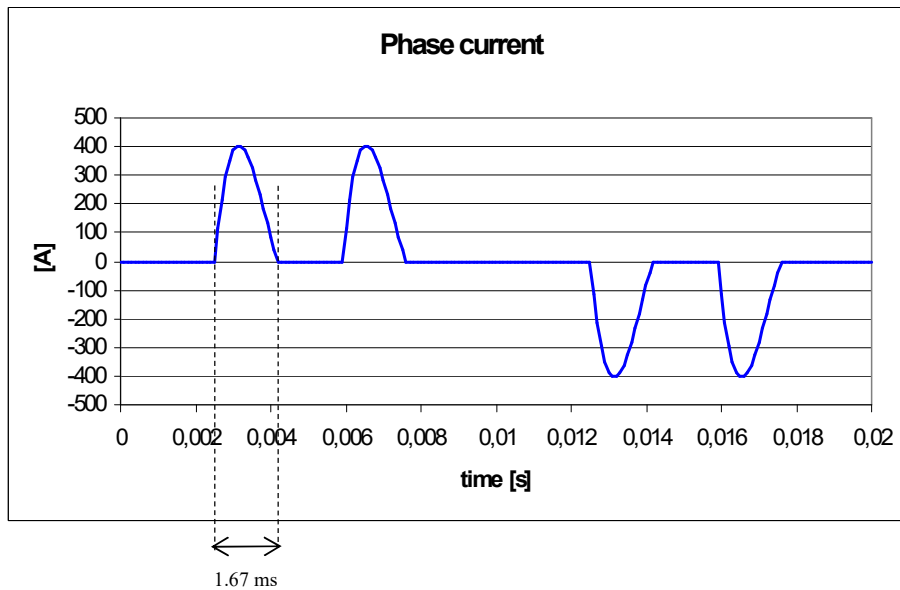


Figure 1

2 Snubbers and converters

- a) Draw an IGBT equipped step down chopper (buck converter) with an RCD snubber. Give a detailed description of how the RCD charge-discharge snubber operates at turn on and at turn-off. Explain why the snubbers are needed (2 p.)
- b) The DC link voltage on the supply side is 250V and the load voltage is 150 V. Calculate the snubber capacitor for the commutation time 0.01ms. The load current is 15 A, assumed constant during the commutation. Calculate the snubber resistor so the discharge time (3 time constants) of the snubber capacitor is less than the IGBT on state time. The switch frequency is 2 kHz (3 p.)
- c) Draw the circuit of a DC supplied 3-level output NPC (neutral point clamping) converter. The answer shall also contain a table with the status (which are on and which are off) of the switches at the three different output voltage levels. (3 p.)
- d) Draw the circuit of a Fly-Back DC/DC converter. The drawing shall contain snubbers at three different positions in the circuit, An explanation is required what the snubbers are protecting from at the three positions. (2 p.)

3 Three Phase

- a) A symmetric three phase voltage:

$$\begin{cases} e_a = \hat{e} \cdot \cos(\omega \cdot t) \\ e_b = \hat{e} \cdot \cos\left(\omega \cdot t - \frac{2\pi}{3}\right) \\ e_c = \hat{e} \cdot \cos\left(\omega \cdot t - \frac{4\pi}{3}\right) \end{cases}$$

Show that these voltages form a rotating vector with constant length and constant speed in the complex (α, β) frame.

(5 p.)

- b) Draw the circuit of a current control block for a generic three phase RLE load. The drawing shall include three phase converter, reference and load current measurement. It must be clear in which blocks the different frame transformations occur.

(5 p.)

4 Current control

A 4-quadrant DC converter is used for current control in a speed control loop with a DC motor. The following parameters are describes the drive.

```
>> La=0.002; % DC motor armature inductance
>> Ra=0; % DC motor armature resistance
>> Udc=400; % DC link voltage
>> Ts = ?? % Sampling time
>>  $\psi_m$  = 1.0; % DC motor magnetizing flux linkage
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- a) Assume that carrier wave modulation of a 4Q converter is used. What carrier wave frequency is required to have a maximum current ripple of 5 Ampère. What is then the sampling time??

(4p)

$di/dt = (U_{dc} - e)/L_a$; $\Delta i = t_p \cdot (U_{dc} - e)/L_a$. Max ripple at $e = w \cdot \psi_m = U_{dc}/2$, i.e. $\Delta i = 1/4 \cdot f_w \cdot (U_{dc} - e)/L_a \rightarrow f_w = 1/4 \cdot \Delta i \cdot (U_{dc} - e)/L = 10/L_a = 5000$; $T_s = 1/2 \cdot f_w = 0.0001$ s.

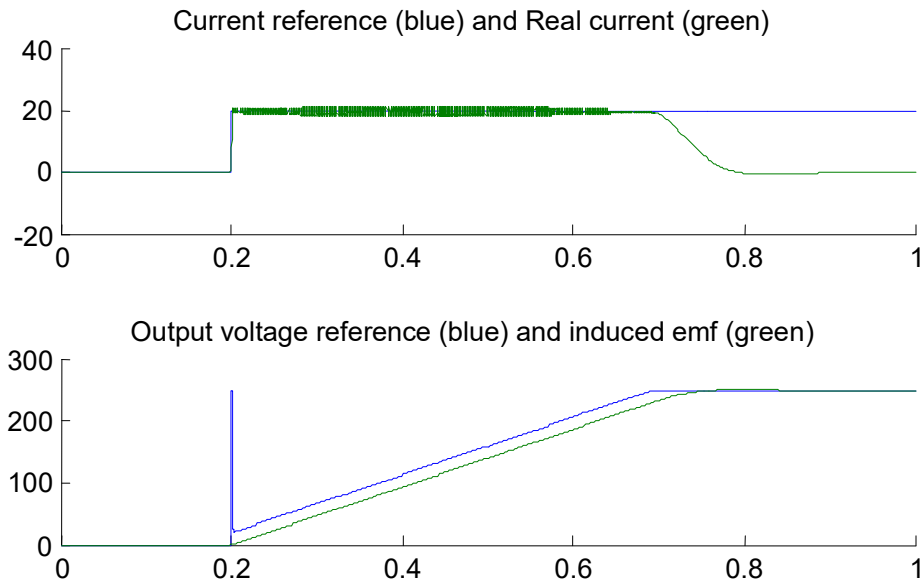
- b) Design a PI current controller for the 4Q converter driving the motor. Assume that acceleration starts with a 0 to 40 Ampère current step from a standstill rotor. Is one sampling interval enough for the current control to eliminate the initial current error, given your assumption of carrier wave frequency from the previous question? If not - how many sampling periods are needed? Assume that there is a current limit at +/- 20 A, and that $\psi_m = 1$.

(4p)

$L_a/T_s = 0.002/0.0001 \cdot 40 = 800$ V, i.e. two periods is needed

- c) In the figure below, a current step response is illustrated with a rotor current limit of 20 A, and the drive is allowed to accelerate freely. Why is the current ripple biggest in the middle of the acceleration and why is the current control lost in the end of the acceleration?

(4p)



$$e = U_{dc}/2, e > U_{dc} - R_a * i$$

5 PM Machine

A permanently magnetized synchronous machine is used as a traction motor.

- a) Which is the fundamental electric stator voltage frequency of a PM machine running at 15000 rpm if it has 8 poles? (2p)

$$f = 15000/60 * 8/2 = 1000 \text{ Hz}$$

- b) Which is the highest phase to phase voltage [RMS] that a 2-level inverter can supply if the DC link is 750 V and symmetric carrier wave modulation is used? (3p)

$$U_{pp} = 750/\sqrt{2} = 530 \text{ [V, RMS]}$$

- c) What is the mechanical base speed of a drive with data according to a) and b) if the flux linkage at the limit of base speed and nominal torque in one phase is 0.149 [Vs, RMS]? (3p)

$$\omega_{el, base} = 530/(0.149 * \sqrt{3}) = 2055 \text{ rad/s}$$

$$n_{mech, base} = \omega_{el, base} / (2\pi) * 60 = 4906 \text{ rpm}$$

- d) With a stator inductance in the x -direction that is smaller than the one in the y -direction, in which quadrant should the stator current vector be positioned to maximize the torque output? (2p)

$$T = \psi_{ipm} * i_{sy} + (L_{sx} - L_{sy}) * i_{sx} * i_{sy} \rightarrow 2^{nd} \text{ and } 3^{rd}$$